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Investigating the Usefulness of Operator Aids for Autonomous Unmanned Ground Vehicles Performing Reconnaissance Tasks

by A. William Evans III

ARL-TR-6651 **September 2013**

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Army Research Laboratory
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14. ABSTRACT
The research described here investigated the ability of operator knowledge management aids to help increase operator performance and reduce perceived workload, providing the potential for increased mission effectiveness. Specifically, the operator aids provided gave information about what an autonomous robotic asset perceived in the environment and the robotic asset's intended actions based on that information. Twenty subjects completed a total of seven experimental missions, using a simulated operator control station called the Warfighter Machine Interface (WMI). The missions included various configurations using three different operator aids. The operator aids included a long-term planner, a short-term planner, and an obstacle map. During the simulated missions, participants managed the autonomous robotic asset while completing a reconnaissance task. In addition, participants were expected to identify when the robotic asset had deviated from its intended course and determine why it had done so. Results of this study showed that the use of operator aids had little effect on operator performance but significantly reduced both cognitive and temporal workload. This reduction in workload, especially with the information presented in the overlays, could let operators take a proactive approach to supervision, rather than simply responding to errors and trouble.

15. SUBJECT TERMS
operator aids, human-robot interaction, operator performance, workload

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1. Introduction

As robotic assets become more complex and autonomous, there are challenges, such as how to keep Soldiers informed about robot activity and intent, as well as maintain overall mission effectiveness, without increasing workload. Soldiers need to be able to quickly gain an understanding of a robotic asset's status when switching from one task to another task (e.g., switching between reconnaissance to area security). Soldiers also need to have some predictive capability about a robotic asset's intended courses of action, so that corrective actions can be taken before an asset gets into trouble. In this study, we investigated the usefulness of operator aids, which overlay information about unmanned ground vehicles' (UGVs') perception and planned route execution onto existing user interfaces, as a way to address these challenges.

The goals of this study were to (1) evaluate the extent to which operator performance and workload is affected by operator aids and (2) evaluate possible interaction effects of operator aid combinations. For the purposes of this study, performance data was based on factors established by Fong et al. (2004) and workload was evaluated as a self-report measure using the NASA-Task Load Index (TLX) (Hart and Staveland, 1988). Additionally, operator preference data were collected to evaluate which of the operator aids were preferred by the participants and why.

1.1 Background

Jameson (2001) described the future Army as involving extensive use of mobile sensing systems, unmanned platforms, and decision aiding systems. He also remarked that information fusion would require an ability to create and maintain real-time situation awareness (SA) from all available information. Operator aids are one way to assist robotic operators in maintaining SA by quickly displaying mission relevant information without requiring too much attention away from primary tasks. Operator aids are display tools, which generate information from data supplied by an autonomous robotic asset to provide an increased understanding of the asset's situation and actions. The intent of operator aids is to reduce the amount of cognitive workload by supplying an operator with information about an asset, in a way that limits the need for additional user cognitive processing, and at the same time increasing an operator's understanding. Wickens' Multiple Resource Theory (1980, 1984) suggests that as workload is increased, specifically in tasks with overlapping cognitive resources (i.e., vision-based tasks, such as reconnaissance or patrol tasks), there would be decreases in performance. Therefore, in a human–robot team reconnaissance task, with a number of highly visual components, it is expected that as workload increases, operator performance will decline. Mitchell and Brennan (in press) reiterate this expectation within their Improved Performance Research Integration Tool (IMPRINT) analysis, predicting large increases in workload for robotic asset operators versus nonoperators. However, we propose that the appropriate use of operator aids can mitigate some of this increased workload and performance decline by improving the information presentation by means of operator aids.

During a reconnaissance mission using a robotic asset, an operator must supervise the asset, observe the mission space, locate and identify potential targets, and record and transmit such information to decision makers up the chain of command. These tasks are in addition to maintaining local area security and any other tasks that may be required outside of those related to the robotic asset. To accomplish all of these tasks, an operator's cognitive resources are sure to be taxed (Mitchell, 2008). Operator aids may lessen the cognitive burden. Specifically, in this research, operator aids will be focused on the presentation of information related to the task of supervising the robotic asset. By providing information about what an autonomous robot calculates as its best route, and why it has calculated that route, operators will have a chance to anticipate trouble spots, provide timely input when needed, and better understand the autonomous system's "intent."

A robot operator who obtains target information gained from a robotic asset's remote sensors represents the first step in providing quality information to decision makers. As such, it is paramount that robot operators are able to focus attention so that the information they provide is as accurate as possible. Operator aids represent tools by which an operator's workload can be reduced, which will allow more resources to be allocated toward other mission critical tasks.

1.2 Hypotheses

Hypotheses for this study have been broken up into (1) hypotheses related to performance and (2) hypotheses related to workload.

1. Four hypotheses predicting improved performance for experimental condition over the control condition have been developed:

   - H_1: Participants will identify simulated targets with greater accuracy.
   - H_2: Participants will identify unmanned ground vehicle (UGV) route deviations with greater accuracy.
   - H_3: Participants will engage tele-operation (tele-op) control less often.
   - H_4: Participants will complete missions in less time.

2. Two hypotheses were formulated in relationship to the workload:

   - H_5: Participants will experience lower levels of perceived workload in the experimental conditions than in the control condition.
   - H_6: Participants' feedback will indicate a preference for operating a robotic asset with operator aids as opposed to having no operator aids available.

2. Methodology

2.1 Instrumentation and Facilities

This study utilized ModSim simulation software, developed by General Dynamics Robotics System (GDRS). This simulation was created as a visualization platform that serves as a basis for realistic simulated experimentation, validation, and refinement of hardware-in-the-loop dynamic planners. This simulation was used in conjunction with the U.S. Army Tank Automotive Research, Development, and Engineering Center's (TARDEC's) Warfighter Machine Interface (WMI), developed by DCS Corp. The WMI is an interface system designed to accommodate a number of different technologies through the use of various tabs for access. Examples of this interface can be seen in figures 1 and 2. Participants monitored the forward-facing camera of the simulated UGV and entered task information using a touch screen monitor. All of the software was run on standard PCs, using two standard 17 inch color monitors.

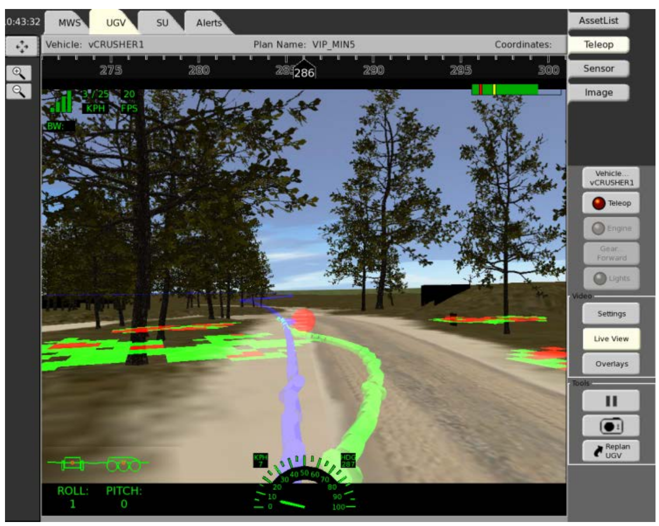

Figure 1. An example of the WMI 3-D interface showing both the short-term (green line) and long-term (blue line) operator aids.

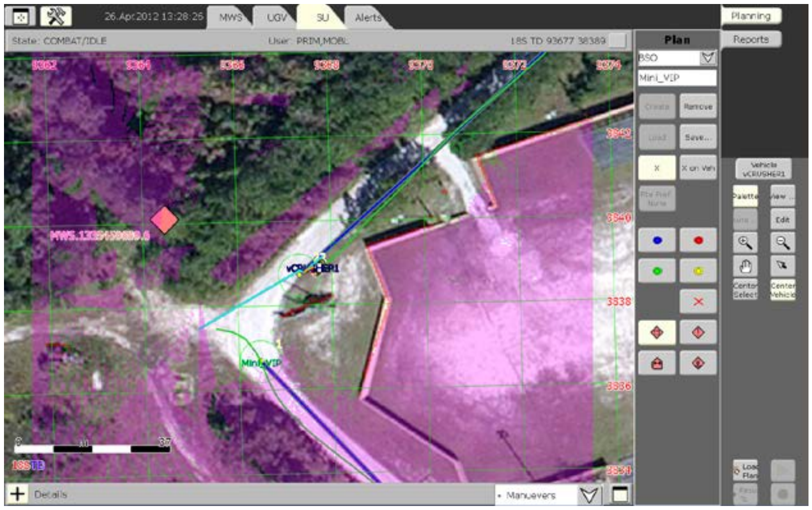

Figure 2. An example of the WMI 2-D interface showing the obstacle map overlay on a top-down map. The edges of obstacle are represented with red dots and the areas shaded with pink are unknown due to an obstructed view from the UGV.

The WMI display has two screens showing different views of the environment. The forward-facing video display is referred to as the three-dimensional (3-D) display. It is called the 3-D display because this display shows a live feed of the environment directly in front of the UGV and allows for a ground level view of the mission space. An example of this can be seen in figure 1. An overhead map view of the environment, referred to as the two-dimensional (2-D) display, shows an overhead "satellite" view of the environment, representative of a 2-D map. The 2-D view also gives users a reference about the UGV's location within the mission space. An example of the 2-D portion of the WMI display can be seen in figure 2. The 2-D and 3-D screens were continuously displayed on the two 17-inch monitors simultaneously, so that participants could attend to either screen at any time during the experiment.

Autonomous navigation for the simulated UGV was handled using GDRS' Autonomous Navigation System (ANS) software. This software was identical to the software used for a real world version of the UGV and allowed the vehicle to navigate an environment via waypoint plan while avoiding environmental obstacles (GDRS, 2013).

2.1.1 Courses or Facilities

This study took place at indoor, office-like locations at the U.S. Army Research Laboratory (ARL) at Aberdeen Proving Ground, MD and DCS Corp. laboratories in Alexandria, VA. Participants completed the study while in a seated position at a computer station approximately 18 inches directly in front of the two display screens.

2.2 Materials and Tests

Participants completed a number of assessments designed to assess their color vision acuity, spatial visualization ability, and spatial orientation ability, as well as a demographic questionnaire to characterize the participant population.

To assess color vision acuity, the Ishihara (1917) color vision test was used (appendix A) as a screening procedure. The color vision test was used to ensure that participants have no unknown color vision deficiencies, as color is an important component of the WMI and operator aids.

Spatial visualization and spatial orientation were assessed using the portions of the Guilford−Zimmerman (1956) attribute survey related to these two areas (appendices B and C). Each of these assessments has been used previously in studies investigating human-robot interaction (HRI) (Fincannon et al., 2008), and have shown positive corollary effects with robot operator performance. These effects indicated that individuals displaying higher levels of spatial ability generally show higher levels of performance when engaging in HRI supervision tasks. The spatial ability scores were used as covariates in the data analysis.

Participants' perceived workload was evaluated after the completion of each mission scenario using the NASA-TLX questionnaire (Hart and Staveland, 1988, see appendix D). The NASA-TLX is a self-report questionnaire of perceived demands in six areas: mental, physical, temporal, effort (mental and physical), frustration, and performance. Participants were asked to rate their perceived workload level in these six areas on 100-point scales, indicated with "high" and "low" ends. The ratings were used to quantify the perceived changes in workload for the various operator aids used.

Finally, participants' operator aid configuration preference and display use was recorded after the seven trials by simply asking each participant what their favorite and least favorite aid configurations were and how much they used the 2-D and 3-D screens.

2.3 Experimental Design

Participants in this study completed a series of reconnaissance missions in which they identified targets from a simulated autonomous UGV platform. Mission navigation of the UGV was fully autonomous, however the UGV platform interface included a variety of operator aids intended to inform the operator about robot intent and robot obstacle identification. Participants only took tele-op (remote) control of the UGV when it was encountering an obstacle (discussed further in the procedure section of this report).

This study employed a 3 (Operator Aid Condition) × 2 (Obstacle Map Condition) + 1 (Control Group of no operator aids) within-subjects design. This design was required due to technology constraints, which limited the application of the Obstacle Map aid, thus not allowing it to be evaluated separately from the other conditions. For analysis purposes, each experimental cell was

compared with the control cell, using a one-way analysis of variance (ANOVA) to test for significance among the seven conditions. This analysis allowed researchers to understand if operator aids presented as a single aid or multiple aids contributed to improved performance over a condition involving no aids.

2.3.1 Independent Variables

Operator Aids. The independent variable levels for Operator Aid Condition were (1) short-term planner (STP) only, (2) long-term planner (LTP) only, and (3) combined short-term and long-term planners (COMBO). Both the STP and LTP were generated using data from the ANS about the path that the automation attempted to follow. The STP operator aid was displayed as a translucent green line overlaid on both forward-facing video stream (3-D) and overhead map (2-D) views of the WMI. The line for the STP operator aid displayed the intended route of the UGV projected for the next several seconds. Similarly, the LTP operator aid was displayed as a translucent blue line overlaid on both forward-facing video stream and overhead map views of the WMI interface. However, the LTP operator aid displayed information about the intended route of the UGV projected for the next several minutes or more. The combination of STP and LTP operator aids simply displayed both translucent green and blue lines at the same time. See figures 1 and 2 for an example of the displays. The two lines representing the STP and LTP may or may not have overlapped, depending on the situation. The actual length of the two lines was dependent upon vehicle speed and varied accordingly.

Obstacle Map. The independent variable levels for Obstacle Map Condition were (1) with the obstacle map overlays and (2) without the obstacle map overlays. Obstacle Maps were generated from laser radar (LADAR) data acquired by the ANS, which were then transformed to display the outlines of physical obstacles in the environment. Scenarios with the obstacle map included translucent overlays on both forward-facing video stream and overhead map views showing obstacles that the UGV had detected. On the video feed view, the obstacle map was represented via red (nonpassable obstacle) and green (passable obstacle) squares at ground level (see figure 1). For the overhead view, obstacle maps were represented using red pixels to show nonpassable obstacle borders and pink translucent shading to indicate unknown areas of the map (see figure 2). Overhead maps were preset at a fixed zoom scale to ensure that all participants received the same view.

2.3.2 Dependent Variables

Dependent variables for this study included (1) number of accurate target identifications, (2) number of unintentional route deviations missed, (3) number of times engaging tele-operation mode, and (4) total mission time. These are all variants of well-established metrics of performance that are frequently used in HRI research (Fong et al., 2004). “Number of accurate target identifications” is defined as the number of correct target locations identified on the overhead map during the performance mission. Target locations were identified by operators touching the location on the interface. “Number of unintentional route deviations missed” is

defined as the total number of times during the performance mission that participants fail to identify, or incorrectly identify, why a deviation from the preplanned mission route has occurred. Responses were recorded from verbal declarations. “Number of times engaging tele-operation mode” is defined as the total number of times the participant engages the tele-operation mode of UGV control during a performance mission. This metric was available from the data logs. Again using information available from data logs, “Total mission time” is defined as the total amount of time, in seconds, it takes to complete a performance mission beginning with the moment that an automated route plan has begun executing to the completion of that plan, including all pauses and occurrences of tele-operation control. All of this information was gathered from either written notes to verbal responses or as .log files created for each mission. The data from these files were reduced and input into statistical software to investigate the appropriate measures.

The NASA-TLX was used to measure ratings of perceived workload, resulting in a composite score derived from six areas of workload (mental, physical, temporal, effort, frustration, and performance). In addition, data were collected about participants’ spatial abilities (via the Guilford−Zimmerman Spatial Aptitude survey) to be used as covariates in data analysis.

Finally, participants’ preferences were recorded for which operator aids were preferred or disliked, as well as utilization data referring to which of the two display screens (2-D or 3-D) was used more. These data were gathered by simply asking each participant at the end of the experiment “which condition was their favorite?”, “which condition was their least favorite?”, and to “estimate the percentage of time spent looking at the 2-D screen and 3-D screen.”

2.4 Procedure

Participants completed seven counterbalanced experimental scenarios designed to explore all of the possible independent variable combinations in the 3 (Operator Aid Combination) × 2 (Obstacle Map Availability) design, plus one control condition that had no operator aids displayed. Once an informed consent was completed, participants were given the color vision test. If participants exhibited any color vision impairment, they would be removed from the study (none did). Next, each participant was given a demographic questionnaire to fill out. Finally, participants were given the two assessments of their spatial ability, one for spatial visualization ability and one for spatial orientation ability.

The participants received a short tutorial on the use of the simulation interface and instructions on how to complete the reconnaissance task. The simulation was a representation of a UGV traversing a predetermined route while participants monitored the displays, searching for targets (represented as “smiley faces”) along the route traveled. Participants were given an opportunity to observe the 2-D and 3-D displays and use the simulation system in a practice scenario to increase familiarity with the system. This gave participants an opportunity to review the various target and obstacle items that they would encounter during the experimental scenarios.

After familiarization and training, participants were asked to act as operator for a UGV on a reconnaissance mission. Each reconnaissance scenario consisted of one UGV following a predetermined route through the urban terrain. Along the route, participants had the opportunity to identify up to six separate targets, still represented as “smiley faces.” In addition to scanning for targets, participants monitored the UGV to ensure that it remained on its intended path. Each mission included a set (three total) of potential obstacles that could cause the UGV’s ANS to deviate from its planned path. These obstacles were positioned randomly throughout the route and consisted of either a patch of tall grass, a person crossing the road, or a Jersey barrier concrete wall. These obstacle types were chosen because they all cause similar issues for current ANS but have different courses of action associated with an encounter. Participants were asked to choose an appropriate course of action (COA) for each obstacle encountered. The three COAs were (1) continue as planned, (2) wait for obstacle to pass and then continue, or (3) reroute the UGV. When tall grass was encountered and caused a route deviation from the plan, the appropriate COA was to instruct the UGV to continue on the planned route without stopping (“continue”). For moving person obstacles, the appropriate COA was to instruct the UGV to wait for the obstacle to clear and then continue on the planned route (“wait and continue”). Finally, if an unexpected Jersey wall appeared as an obstacle, a new route was needed to be planned (“reroute”). COAs were executed by speaking aloud the obstacle type being encountered and then operating the UGV with the appropriate maneuver for the given obstacle. At the end of each of the seven scenarios, NASA-TLX data was collected and at the completion of all the scenarios, user preference and use data were collected via interview.

3. Performance Data Results and Analysis

For this study, Noncommissioned Officers (NCOs) and civilians from the local ARL population were recruited as participants. A total of 20 individuals participated. Participants included 15 males and 5 females with an average age of 32.2 years (standard deviation = 6.895). Of the 20 total participants, four were active duty NCOs in the U.S. Army and one was a cadet at the U.S. Military Academy.

To investigate the performance-related hypotheses, comparisons of the experimental conditions against the control were completed for each of the dependent variables, analyzed with one-way ANOVAs using Statistical Package for the Social Sciences (SPSS) version 19.0. Results of the individual ANOVAs are presented in the following sections.

3.1 Target Identification

A one-way ANOVA was conducted to evaluate the effect of Operator Aid Condition on participants' ability to accurately identify targets in the experimental environment. Results of the ANOVA showed no significant differences among the experimental conditions ($F(6,90)$ = 1.652, p = 0.142). To ensure that other factors were not influencing the analysis, covariate data was used in a followup ANCOVA analysis. Covariates were derived from the two spatial ability evaluations: spatial orientation and spatial visualization. The covariates, representing an individual participant's spatial ability, were derived from the total number of correct answers given per questionnaire. The covariate analysis was used to control specifically for ability, because it is known that spatial ability is positively correlated with robotic operator performance (Fincannon et al., 2008). Therefore, the results for differences in performance should be attributed to the experimental conditions (i.e., operator aids) and not just because the participants might have differed in innate ability. The same approach for covariates was used for each of the performance measure analysis (sections 3.1–3.4). Results of the ANCOVA showed no significant influence from any of the covariates and no significant differences in the results ($F(6,78)$ = 0.607, p = 0.724) and therefore unadjusted data were used for analysis. The data from this analysis have been summarized in table 1.

Table 1. Means and standard deviations for target identification data in the seven conditions (measured in correct identifications per mission, i.e., larger score is better. maximum = 6).

Condition	Mean	Standard Deviation
C1: Short-term and obstacle map	4.75	1.24
C2: Short-term only	5.00	0.97
C3: Long-term and obstacle map	4.38	1.54
C4: Long-term only	4.63	1.46
C5: Short-term, long-term, and obstacle map	4.69	1.62
C6: Short-term and long-term	4.31	1.49
C7: No operator aids	3.88	1.54

3.2 Route Deviations

A one-way ANOVA was conducted to evaluate the effect of the operator aid condition on participants' ability to accurately identify UGV unintentional route deviations in the experimental environment. Results of the ANOVA showed no significant differences in the experimental conditions ($F(6,114)$ = 1.029, p = 0.410). To ensure that other factors were not influencing the analysis, covariate data was used in a follow up ANCOVA analysis. The same approach for covariates was used as explained in section 3.1. Results of the ANCOVA showed no significant influence from any of the covariates and no significant differences in the results ($F(6,102)$ = 0.677, p = 0.669). The data from this analysis have been summarized in table 2.

Table 2. Means and standard deviations for unintentional route deviation data in the seven conditions (measured in number of missed route deviations per mission, i.e., smaller score is better. minimum = 0).

Condition	Mean	Standard Deviation
C1: Short-term and obstacle map	0.40	0.503
C2: Short-term only	0.40	0.503
C3: Long-term and obstacle map	0.35	0.587
C4: Long-term only	0.30	0.470
C5: Short-term, long-term, and obstacle map	0.30	0.470
C6: Short-term and long-term	0.25	0.444
C7: No operator aids	0.60	0.598

3.3 Tele-Operation Occurrences

A one-way ANOVA was conducted to evaluate the effect of Operator Aid Condition on participants' use of the tele-operation control mode in the experimental environment. Results of the ANOVA showed no significant differences in the experimental conditions ($F(6,114) = 0.533$, $p = 0.782$). To ensure that other factors were not influencing the analysis, covariate data, as previously described, was used in a follow up ANCOVA analysis. Results of the ANCOVA showed no significant influence from any of the covariates and no significant differences in the results ($F(6,102) = 0.564$, $p = 0.758$). The data from this analysis have been summarized in table 3. Based on scenario design, we expected that each individual would have a minimum of three tele-operation occurrences per mission.

Table 3. Means and standard deviations for tele-operation occurrences data in the seven conditions (measured in number of times tele-operation mode was engaged per mission, i.e., smaller score is better).

Condition	Mean	Standard Deviation
C1: Short-term and obstacle map	3.50	1.00
C2: Short-term only	4.00	0.86
C3: Long-term and obstacle map	3.75	1.02
C4: Long-term only	3.80	0.77
C5: Short-term, long-term, and obstacle map	3.80	0.89
C6: Short-term and long-term	3.70	0.66
C7: No operator aids	3.75	1.21

3.4 Total Mission Time

Finally, a one-way ANOVA was conducted to evaluate the effect of the Operator Aid Condition on overall mission time. Results of the ANOVA showed no significant differences in the experimental conditions ($F(6,102) = 0.714$, $p = 0.639$). To ensure that other factors were not influencing the analysis, covariate data was used in a follow up ANCOVA analysis. Covariates were derived from the spatial ability evaluations mentioned earlier and scored as described

above. Results of the ANCOVA showed no significant influence from any of the covariates and no significant differences in the results (*F(6,90)* = 0.725, p = 0.630). The data from this analysis have been summarized in table 4.

Table 4. Means and standard deviations for total mission time data in the seven conditions (measured in total seconds from beginning of automated plan execution to completions of plan per mission, i.e., less time is better).

Condition	Mean	Standard Deviation
C1: Short-term and obstacle map	406.98	34.50
C2: Short-term only	401.28	50.57
C3: Long-term and obstacle map	412.11	39.51
C4: Long-term only	398.26	37.32
C5: Short-term, long-term, and obstacle map	406.21	30.93
C6: Short-term and long-term	419.38	35.08
C7: No operator aids	404.96	38.53

4. Workload Data Analysis

To investigate the workload hypothesis, comparisons of the experimental conditions against the control were completed. NASA-TLX composite scores, calculated by summing the six subscale scores and dividing by 6 (highest possible score is 100), were calculated and then analyzed with a one-way ANOVA using SPSS 19.0 to evaluate the effects of the Operator Aid Condition on self-reported workload as measured by the NASA-TLX. Results of the ANOVA showed a significant effect existed (*F(6,114)* = 97.188, p < 0.001), among the self-reported workload measures for the different Operator Aid Conditions.

Post hoc analysis, using paired sample t-test ($t(19) = -2.071$, p = 0.026, one-tailed) and Tukey HSD correction for Type I error showed that the condition with the STP and LTP operator aids only (Condition 6: short-term planner, long-term planner, no obstacle map) yielded significantly lower composite workload scores than the control condition without any operator aids (Condition 7). A marginal finding involved the condition that included both long-term and short-term planners and the obstacle map (Condition 5). T-test analysis ($t(19) = -1.676$, p = 0.055, one-tailed) showed this condition to yield lower amounts of self-reported workload than the control condition (Condition 7), though these results were not significant even with the benefit of a one-tailed test. No other results showed significance. These results are depicted in figure 3.

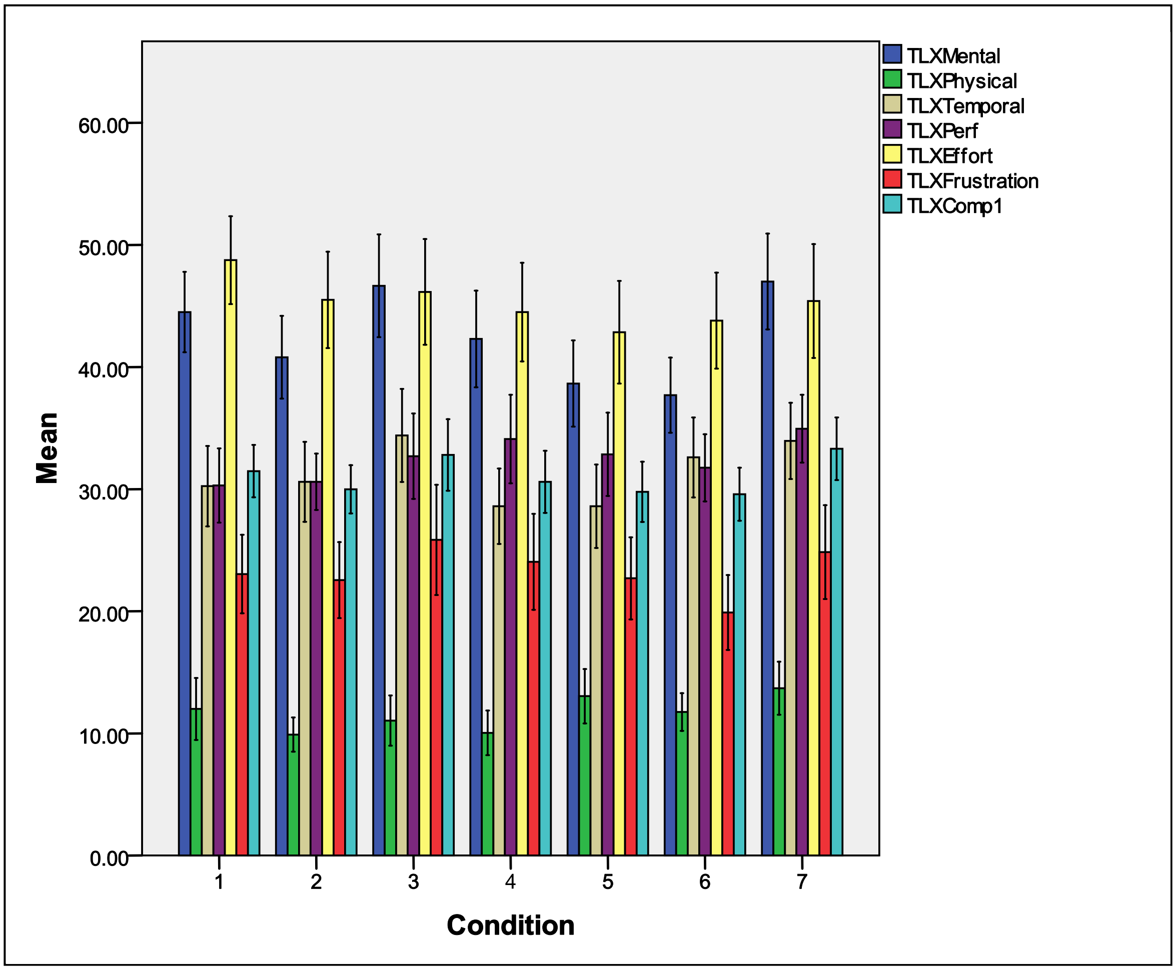

Figure 3. Means plot for NASA-TLX scores by experimental condition (1= Short-Term Planner and Obstacle Map; 2= Short-Term Planner only; 3= Long-Term Planner and Obstacle Map; 4= Long-Term Planner only; 5= Short-Term Planner, Long-Term Planner, and Obstacle Map; 6= Short-Term Planner and Long-Term Planner; 7 = Control – no operator aids).

A significant workload composite score result prompted analyses of the individual workload subscales (as suggested by Hill et al. [1992]) to determine what specific subscales of workload were affected by the inclusion of the aids. The analyses revealed that only two of the NASA-TLX subscales showed significant results: mental workload and temporal workload. All subscale results are shown for completeness, including no significant results. For each subscale, a maximum rating is 100. Table 5 shows the scores for each subscale and the composite score.

Table 5. Mean scores for the composite NASA-TLX and subscales by experimental condition.

	Composite	Mental	Physical	Temporal	Performance	Effort	Frustration
Condition 1	31.47	44.50	12.00	30.25	30.30	48.75	23.05
Condition 2	30.00	40.80	9.90	30.60	30.60	45.50	22.55
Condition 3	32.80	46.65	11.05	34.40	32.70	46.15	25.85
Condition 4	30.60	42.30	10.05	28.60	34.10	44.50	24.05
Condition 5	29.78	38.65	13.05	28.60	38.85	42.85	22.70
Condition 6	29.58	37.70	11.75	32.60	31.75	43.80	19.90
Condition 7	33.31	47.00	13.70	33.95	34.95	45.40	24.85

Notes: Maximum = 100. 1= Short-Term Planner and Obstacle Map; 2= Short-Term Planner only; 3= Long-Term Planner and Obstacle Map; 4= Long-Term Planner only; 5= Short-Term Planner, Long-Term Planner, and Obstacle Map; 6= Short-Term Planner and Long-Term Planner; 7= Control – no operator aids.

4.1 Mental Workload

A one-way ANOVA was conducted to evaluate the effect of the Operator Aid Condition on self-reported mental workload as reported using the NASA-TLX. It showed significant differences ($F(6,114) = 82.955$, $p < 0.001$) among experimental conditions (see figure 4).

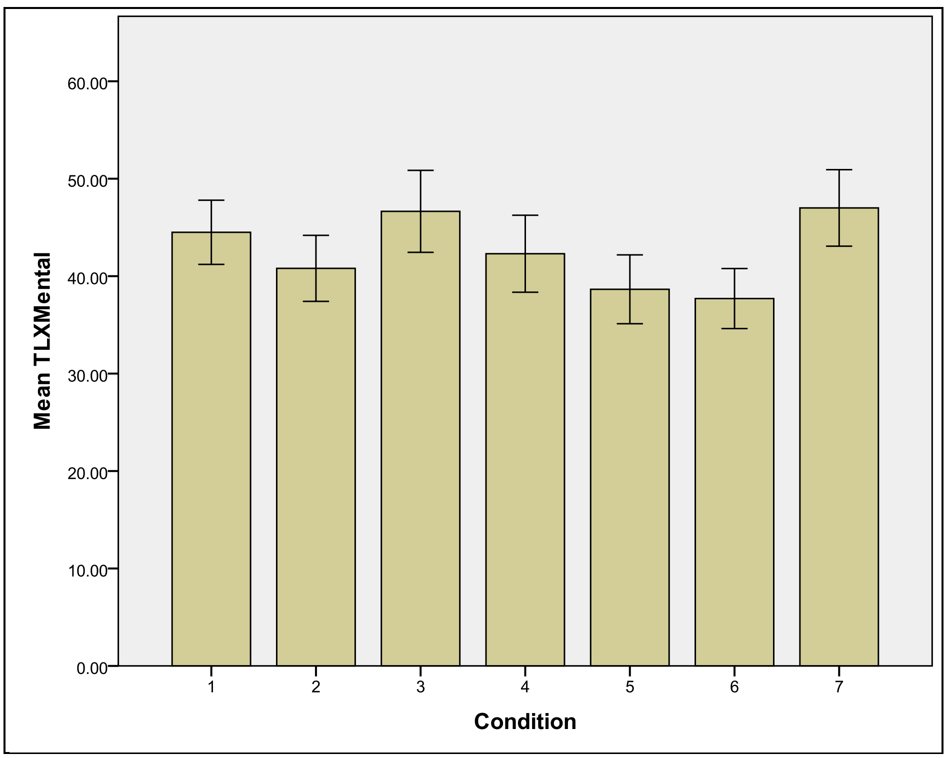

Figure 4. Means plot for NASA-TLX Mental Workload scores by experimental condition (1= Short-Term Planner and Obstacle Map; 2= Short-Term Planner only; 3= Long-Term Planner and Obstacle Map; 4= Long-Term Planner only; 5= Short-Term Planner, Long-Term Planner, and Obstacle Map; 6= Short-Term Planner and Long-Term Planner; 7= Control – no operator aids).

Post hoc analysis, using paired sample t-test ($t(19) = -1.953$, $p = 0.033$, one-tailed) and Tukey HSD correction for Type I error showed that the condition in which all three of the operator aids (short-term planner, long-term planner, and obstacle map; Condition 5) were present and yielded significantly lower mental workload than the control condition without any operator aids (Condition 7). The only other experimental condition to show significant results was the condition that included both long-term and short-term planners but without the aid of the obstacle map (Condition 6). T-test analysis ($t(19) = -2.374$, $p = 0.014$, one-tailed) showed this condition to yield significantly lower amounts of self-reported mental workload than the control condition (Condition 7). No other experimental conditions compared to the control condition yielded significant results in terms of mental workload.

4.2 Physical Workload

A one-way ANOVA was conducted to evaluate the effect of the Operator Aid Condition on self-reported physical workload as reported using the NASA-TLX. It showed no significant differences ($F(6,114) = 0.241$, $p = 0.962$) among experimental conditions.

4.3 Temporal Workload

A one-way ANOVA was conducted to evaluate the effect of the Operator Aid Condition on self-reported temporal workload. Results of the ANOVA showed a significant effect existed ($F(6,114) = 7.993$, $p = 0.012$) among the self-reported workload measures for temporal demand.

Post-hoc analysis, using paired sample t-test ($t(19) = -2.374$, $p = 0.014$, one-tailed) and Tukey HSD correction for Type I error showed that, again, the condition in which all three of the operator aids (short-term planner, long-term planner, and obstacle map; Condition 5) were present yielded significantly lower temporal workload than the control condition without any operator aids (Condition 7). One other experimental condition showed significant results for temporal workload, the condition that included only the long-term planner aid (Condition 4). T-test analysis ($t(19) = -1.752$, $p = 0.050$, one-tailed) showed this condition to yield significantly lower amounts of self-reported temporal workload than the control condition (Condition 7). No other experimental conditions compared to the control condition yielded significant results in terms of temporal workload (see figure 5).

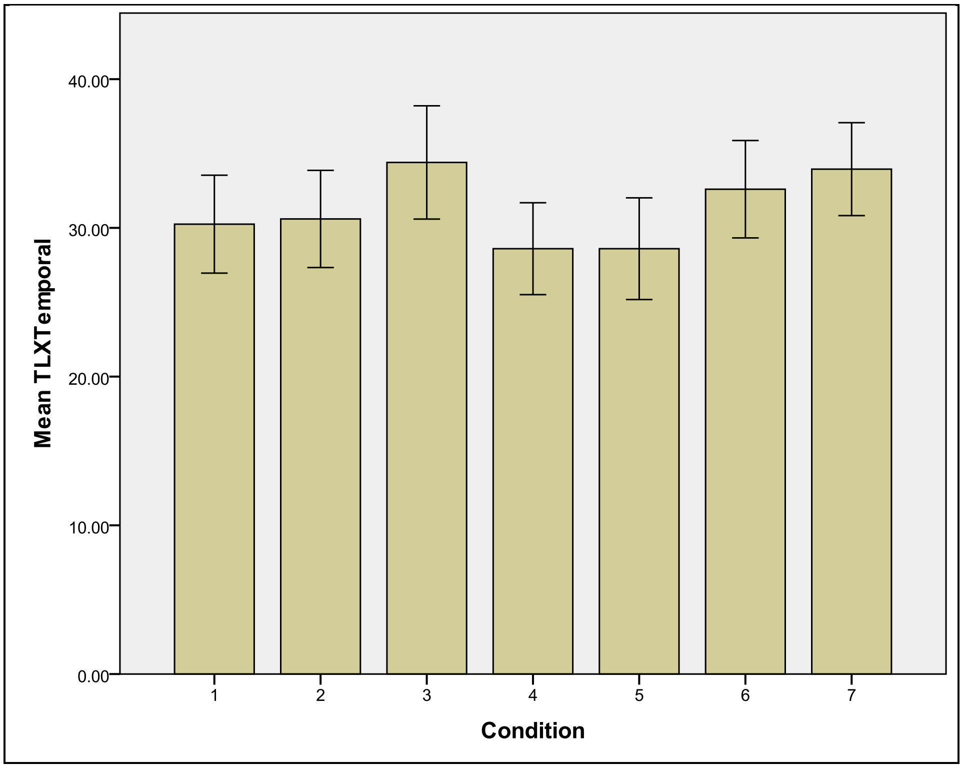

Figure 5. Means plot for NASA-TLX Temporal Workload scores by experimental condition (1= Short-Term Planner and Obstacle Map; 2= Short-Term Planner only; 3= Long-Term Planner and Obstacle Map; 4= Long-Term Planner only; 5= Short-Term Planner, Long-Term Planner, and Obstacle Map; 6= Short-Term Planner and Long-Term Planner; 7= Control – no operator aids).

4.4 Performance Workload

A one-way ANOVA was conducted to evaluate the effect of the Operator Aid Condition on self-reported performance as reported using the NASA-TLX. It showed no significant differences ($F(6,114$ = 0.146, p = 0.990) among experimental conditions.

4.5 Effort Workload

A one-way ANOVA was conducted to evaluate the effect of the Operator Aid Condition on self-reported effort as reported using the NASA-TLX. It showed no significant differences ($F(6,114)$ = 0.100, p = 0.996) among experimental conditions.

4.6 Frustration Workload

A one-way ANOVA was conducted to evaluate the effect of the Operator Aid Condition on self-reported frustration as reported using the NASA-TLX. It showed no significant differences ($F(6,114)$ = 0.133, p = 0.992) among experimental conditions.

4.7 User Preferences

4.7.1 Operator Aid Condition

Participants preferences were evaluated for which of the conditions were their favorite and least favorite to use, based on the poststudy interview questions described in section 2.3. Although the choices for favorite condition were more varied, the majority of the choices (18 of 20 participants) included experimental conditions that involved at least two of the three operator aids. Additionally, the majority of subjects (15 of 20) listed the control condition, which had no operator aids as their least favorite condition (see table 6).

Table 6. Participant's favorite and least favorite operator aid configurations.

Conditions	Favorite Condition	Least Favorite Condition
Short- and long-term planners with obstacle map	4	1
Short-term planner and obstacle map	7	2
Long-term planner and obstacle map	3	0
Short-term and long-term planners	4	0
Short-term planner only	0	1
Long-term planner only	1	1
No operator aids (control)	1	15

4.7.2 2-D (Overhead View) vs. 3-D (Forward-Facing View) Use

As part of the post study interview questions described in section 2.3, participants reported using both the 3-D (front-facing view) and 2-D (overhead view) displays to complete the task but with varying frequency. Results show that 3-D display was reported as being used more than 70% (mean = 71.1%, standard deviation = 13.5) of the time during missions, whereas the 2-D display was used less than 30% (mean = 28.9%, standard deviation = 13.5) of the time. This information gives researchers a baseline to understand how operators are using the 2-D and 3-D views to complete the mission tasks. Additionally, this information could be used to determine how best to present various operator aid types and how they are most useful.

5. Discussion

5.1 Performance

Results of the performance data analysis failed to support any of the four hypotheses associated with the performance measurements. This failure to observe any significant differences may be due to several factors. A relatively simple task could have affected results. Additionally, participants in this study received a minimum amount of training and were exposed to the operator aids for only a short time. More training and exposure might help users to better understand the operator aids and could lead to the formulation of strategies to further increase the aids' usefulness.

One factor that may have played a significant role in the performance results is the nature of the obstacles that were used. Two of the obstacles, Jersey barriers and pedestrians, were very salient and perhaps did not benefit much from the use of operator aids. The tall grass obstacle was much more ambiguous to the robot and provided a more unique challenge about which participants needed to make a decision. Future research should focus on more ambiguous obstacles, such as the tall grass, which may or may not cause issues for an autonomously navigating robot.

However, it should be noted that although the use of operator aids did not increase performance, nor did the inclusion of aids reduce operator performance. Thus, the need for operators to attend to additional information provided by the aids did not produce negative effects on performance.

5.2 Workload

Results of this study yielded some interesting results about reported operator workload and the use of the operator aids. Significant results showed that a combination of operator aids helped to reduce self-reported operator workload. Interestingly, even with more overall information to attend to, operators were able to reduce their perceived workload in regards to the robotic asset under their control. Participants in this study commented that the long-term and short-term planners gave them a good idea of where the robot was trying to get to and the addition of the obstacle map let them know why, based on what the robot was "seeing."

Looking at the individual workload measures revealed mental and temporal workload as key in the overall reduction of workload. This could be seen as an indicator about participants' belief that the operator aids made it easier for them to understand the robotic assets actions and intents in a quick and efficient manner. Not surprisingly, physical workload was not affected, given the primarily cognitive nature of the task. Additionally, the lack of significant results for performance, effort, and frustration may be due to the relative simplicity of the task. In future research, more difficult, complex, or taxing tasks may see different results and are worth studying.

We do not fully understand the "spike" in the composite workload index for the long-term planner and Obstacle Map Condition (Condition 3). At this time, it is unknown why the LTP and Obstacle Map condition was rated as higher workload than LTP by itself (Condition 4) and as high as the control condition (Condition 7).

Further, the overall workload results remained relatively low across conditions throughout the study. This is a sign that the task itself may have been not challenging enough to produce significant workload challenges for the participants. If the task was shown to be too easy, this also may explain why the covariate measures, which have been shown to be significant in previous studies, did not yield any significant results here. That is, all participants could perform the tasks well, regardless of their individual spatial ability. In future studies, task difficulty should be advanced to levels that ensure an appropriate amount of workload so that "floor effects" such as these aren't a factor.

The results from the workload measure analysis were also supported by the evaluation of user preferences. The preferences indicated that operators preferred having information coming from multiple aids to help them gain a complete understanding of the situation.

The results from the 3-D versus 2-D usage question provide ideas about how operators would spend their time monitoring the views provided by a robotic asset. The majority of operators' time in this study was spent on the 3-D display; however, the exact reason is still not known. Future research should investigate if this preference was due to the usefulness or effectiveness of the aids in one display type versus another (e.g., 3-D displays provide more meaningful information) or simply a byproduct of how quickly information could be understood in one display type versus another (e.g., 2-D displays conveyed relevant information to operators in a more simple and quick way to comprehend).

5.3 Conclusions

Overall, even with a lack of significant performance outcomes, other results of this research may be viewed positively in that operator aids were shown to create an environment in which operators can reduce cognitive and temporal workload, although without differences in performance. Again, more extensive training in the use of the operator aids and development of strategies in the use of the aids might help to realize greater improvements in workload reduction along with potential performance increases.

We plan to conduct a similar study using operator aids in a field study environment with Soldier participants. This field study's results will be compared against this current study to support (or contradict) the current findings. Another area of interest moving forward with this research is trust. Operator aids may be able to engender trust of Soldiers in robotic assets. By creating more salient interfaces for robotic assets, Soldiers could have a greater understanding of robotic assets and their inner workings. This understanding could then help Soldiers to maintain higher levels of appropriate trust, and therefore mission effectiveness, within human-robot teams (Kim and Hinds, 2006).

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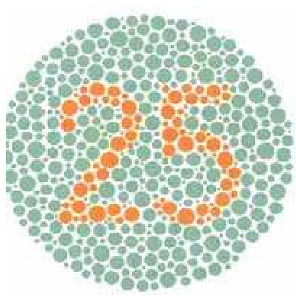
Appendix A. Examples of Ishihara Color Vision Assessment

This appendix appears in its original form, without editorial change.

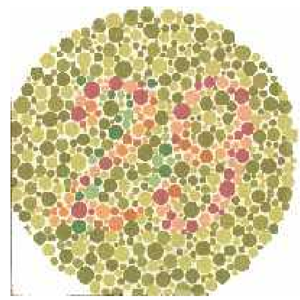
Color Vision Test

What numbers do you see revealed in the patterns of dots below? Please record the number on the answer sheet or, if you do not see a number, write “NONE.”

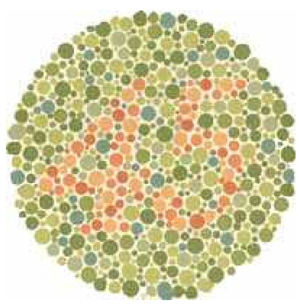
Question 1



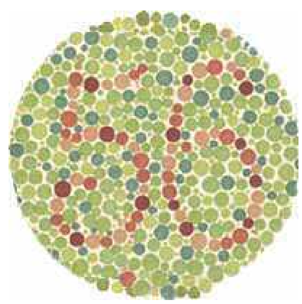
Question 2



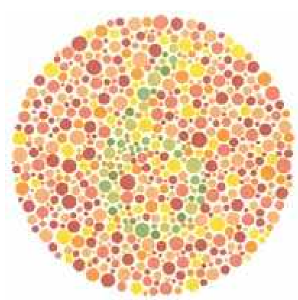
Question 3



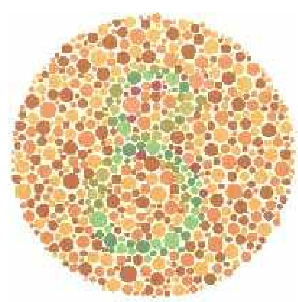
Question 4



Question 5



Question 6

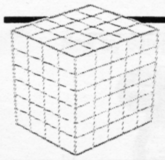


Please turn the page to continue. . .

Appendix B. Example of Guilford−Zimmerman Spatial Visualization Assessment

This appendix appears in its original form, without editorial change.

The Guilford-Zimmerman Aptitude Survey



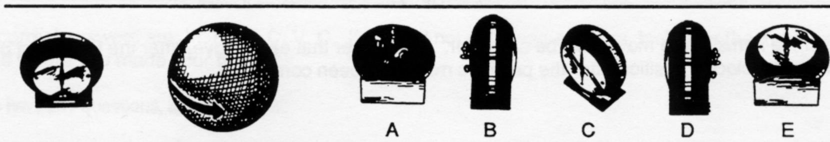
Part 6/Spatial Visualization

Name ______________________ Date ________ Score ________ Sex: M F

INSTRUCTIONS.
This is a test of how well you are able to visualize spatial position. In each item you are to note how the clock would move if it were moved as indicated by the arrow on the sphere.

Here are some sample items.

I



A B C D E

The first picture at the left shows a clock. Next to it is a sphere with an arrow marked on it. The arrow shows how the clock is to be moved. This move is illustrated (in two steps) in the picture below. When the clock is moved to the one-quarter turn shown by the arrow, it is then in position B. B is therefore the correct answer. You would record this by darkening the answer space right below B on your answer sheet. (But do not record answers to sample items.)

Original Position

Position after the move has been completed

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Appendix C. Example of Guilford−Zimmerman Spatial Orientation Assessment

This appendix appears in its original form, without editorial change.

The Guilford-Zimmerman Aptitude Survey

Part 5/Spatial Orientation

Name ______________________ Date ________ Score ________ Sex: M F

INSTRUCTIONS.

This is a test of your ability to see changes in direction and position. In each item you are to note how the position of the boat has changed in the second picture from the original position in the first picture.

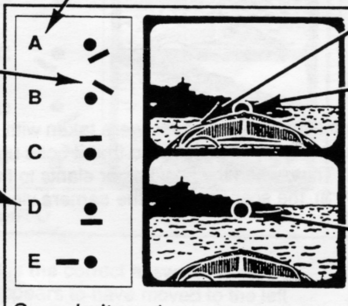
Here is Sample Item 1.

These are the five possible answers to the item.

These bars represent the boat's prow.

This is the correct answer. It shows that the prow of the boat has dropped below the aiming point.

(If the prow had risen, instead of dropped, the correct answer would have been C, instead of D.)



Sample Item 1

This is the prow (front end) of a motor boat in which you are riding.

This is the aiming point. It is the exact spot you would see on land if you sighted right over the point of the prow.

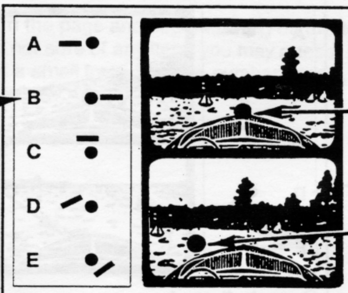
This is the same aiming point shown above. Note that the prow has dropped below it.

To work each item: **First**, look at the top picture and see where the motor boat is headed. **Second**, look at the bottom picture and note the CHANGE in the boat's heading. **Third**, mark the answer that shows the same change on the separate answer sheet.

Try Sample Item 2.

This also shows that the prow of the boat is to the right of the aiming point. So, it is the correct answer.

(If the boat had turned to the left, instead of to the right, the correct answer would have been A.)



Sample Item 2

This is the aiming point.

This is the same aiming point. The motor boat is now headed to the right of it.

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Appendix D. Example of NASA-TLX Perceived Workload Assessment

This appendix appears in its original form, without editorial change.

RATING SCALE DEFINITIONS

TITLE	ENDPOINTS	DESCRIPTIONS
MENTAL DEMAND	LOW/HIGH	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	LOW/HIGH	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	LOW/HIGH	How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	GOOD/POOR	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	LOW/HIGH	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	LOW/HIGH	How insecure, discouraged, irritated stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

Scoring Form 1

1. Mental Demand - Individual

Low High

2. Physical Demand - Individual

Low High

3. Temporal Demand - Individual

Low High

4. Performance - Individual

Good Bad

5. Effort - Individual

Low High

6. Frustration - Individual

Low High

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List of Symbols, Abbreviations, and Acronyms

2-D	two-dimensional
3-D	three-dimensional
ANOVA	analysis of variance
ANS	Autonomous Navigation System
ARL	U.S. Army Research Laboratory
ATO	Army Technology Objective
COA	course of action
COMBO	combined short-term and long-term planners
GDRS	General Dynamics Robotics System
HRI	human-robot interaction
IMPRINT	Improved Performance Research Integration Tool
LADAR	laser radar
LTP	long-term planner
NCO	Noncommissioned Officer
OM	obstacle map
SA	situation awareness
SOURCE	Safe Operations Using Robotic in Complex Environments
SPSS	Statistical Package for the Social Sciences
STP	short-term planner
TARDEC	Tank Automotive Research, Development, and Engineering Center
TLX	Task Load Index
UGV	unmanned ground vehicle
WMI	Warfighter Machine Interface

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1 (PDF)	ARMY G1 DAPE MR B KNAPP 300 ARMY PENTAGON RM 2C489 WASHINGTON DC 20310-0300

ABERDEEN PROVING GROUND

13 (PDF)	DIR USARL RDRL HR L ALLENDER P FRANASZCZUK C COSENZO RDRL HRM P SAVAGE-KNEPSHIELD RDRL HRM AL C PAULILLO RDRL HRM B C SAMMS RDRL HRM C L GARRETT RDRL HRS J LOCKETT RDRL HRS B M LAFIANDRA RDRL HRS C K MCDOWELL RDRL HRS D B AMREIN RDRL HRS E A EVANS D HEADLEY

INTENTIONALLY LEFT BLANK.